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# **Medical Updates to the International Space Station Probabilistic Risk Assessment Model Using the Integrated Medical Model**

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Presenters:

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**Presentation to the Multilateral Medical Operations Panel**

NASA Johnson Space Center

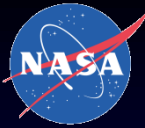
SLSD/SD/SD4/Wyle

Houston, TX

4 May 2011

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# Purpose/Agenda



- **Purpose:** To inform the MMOP of the current IMM capability, and present the updated medical risk estimates approved for use by the Space Station Program.
- **Select the appropriate box below:**
  - ☐ Request for Technical Concurrence
  - ☐ Request for Partial Implementation
  - ☐ Request for Full/Final Implementation
  - ☒ **Information Only/Management Direction**
  - ☐ Response to an Action Item

**This presentation was previously reviewed/dispositioned at:**

<u>Meeting</u>	<u>Date</u>	<u>Outcome/Direction</u>
Space Medicine CCB	May 2010	Approved. Present to FACB
Flight Activities Control Board	June 2010	Present to NASA HQ/HMTA
Health & Medical Technical Authority	June 2010	Approved
Safety & Mission Assurance CCB	Dec 2010	Present to SSPCB
Space Station Control Board	Dec 2010	Approved. Present to MMOP

# Life Before IMM

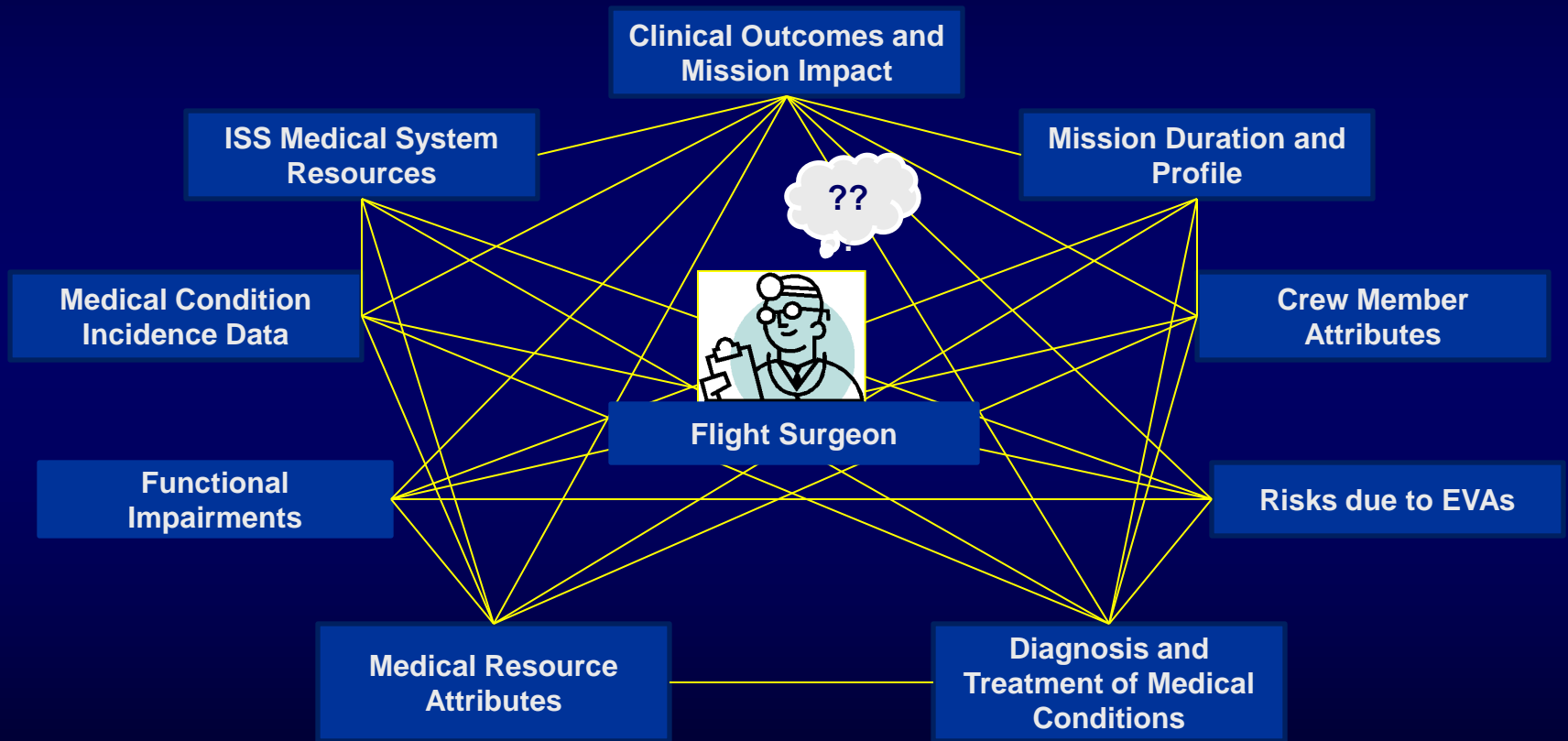


What is the likelihood of a medical evacuation?

What is the risk of Loss of Crew Life due to illness on ISS?

What medical devices should we have on ISS?

What should be in the Expedition Medical Kit?



# Life Now with IMM



## Mission Specific Inputs

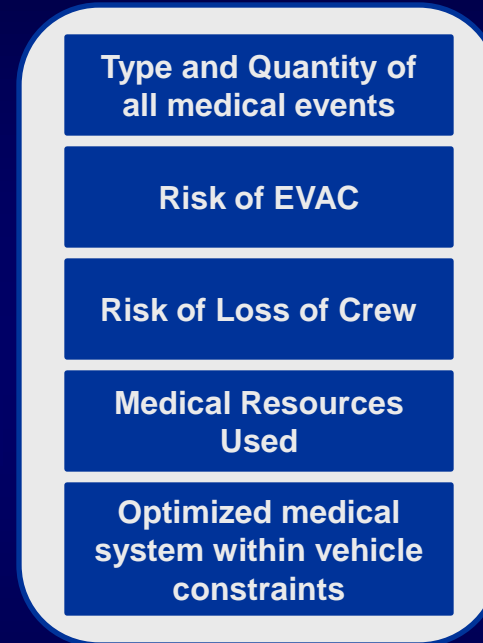


## Monte Carlo Simulations



13,500+ data elements

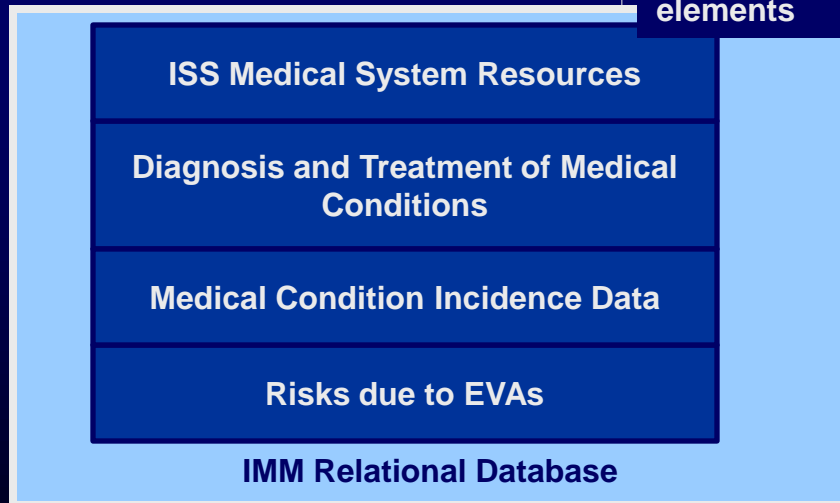
## Quantified Outputs



## Informed Analysis



Flight Surgeon



- IMM Approach
  - Represents specific (83) medical conditions (including nine space adaptation conditions)
  - Accounts for ISS-based medical capability
  - Bounds clinical outcome uncertainty via best-case, worst-case, and untreated-case scenarios
- IMM development started in June 2005, and funded by Human Research Program
- Transitioned from research to ops, Feb 2011
- Provides evidence-based optimization of in-flight medical system mass and volume



# Release History

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- FY 2005 Project Kickoff
  - April 2008 Project Technical Review
  - Sept 2008 IMM v1.0 – Proof of Concept Complete
  - Oct 2008 Conceptual Model Review
  - Mar 2009 Software Transition from Crystal Ball to SAS 9.1
  - Sept 2009 IMM v2.0 – Beta version of relational database
  - Oct 2010 IMM v3.0 - Integrated with Database
  - Dec 2010 ISS Program Accepts Risk Forecasts
  - Feb 2011 Transition to Operational Tool
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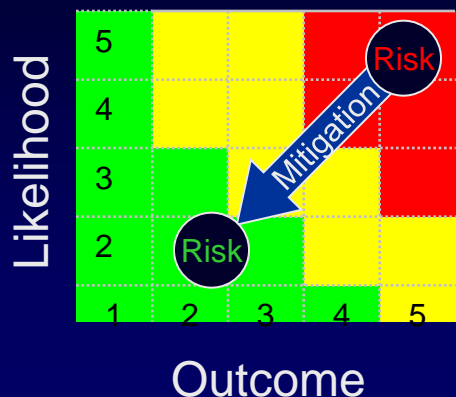
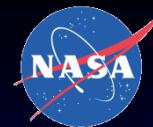
# IMM Evidence Base

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- Astronaut Health Database
- ISS Expeditions 1 thru 13 (2006)
- STS-01 thru STS-114 (2005)
- Apollo, Skylab, Mir (U.S. crew only)
- Analog, terrestrial data
- Review of crew medical charts
- Flight Surgeon Subject Matter Expertise
- **Russian medical data not used**

# Comparison – 5x5 Risk Matrix vs. IMM



## 5x5 Matrix

- Qualitative
- Categorical
- Subjective
- Single Risk
- No Uncertainty
- No Confidence Interval
- Limited context

## IMM

- Quantitative
- Probabilistic, Stochastic
- Evidence-based
- Integrated Risks
- Uncertainty
- Confidence Interval
- In context

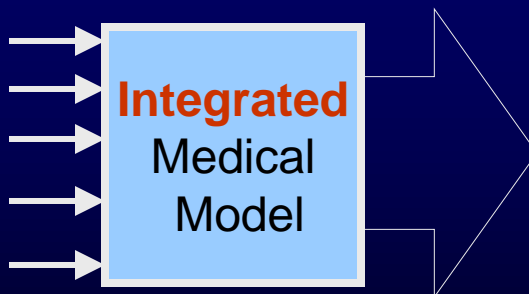
▪ Medical Conditions & Incidence Data

▪ Crew Profile

▪ Mission Profile & Constraints

▪ Potential crew impairments and mission end states

▪ In-flight Medical Resources



▪ Type and quantity of all medical events

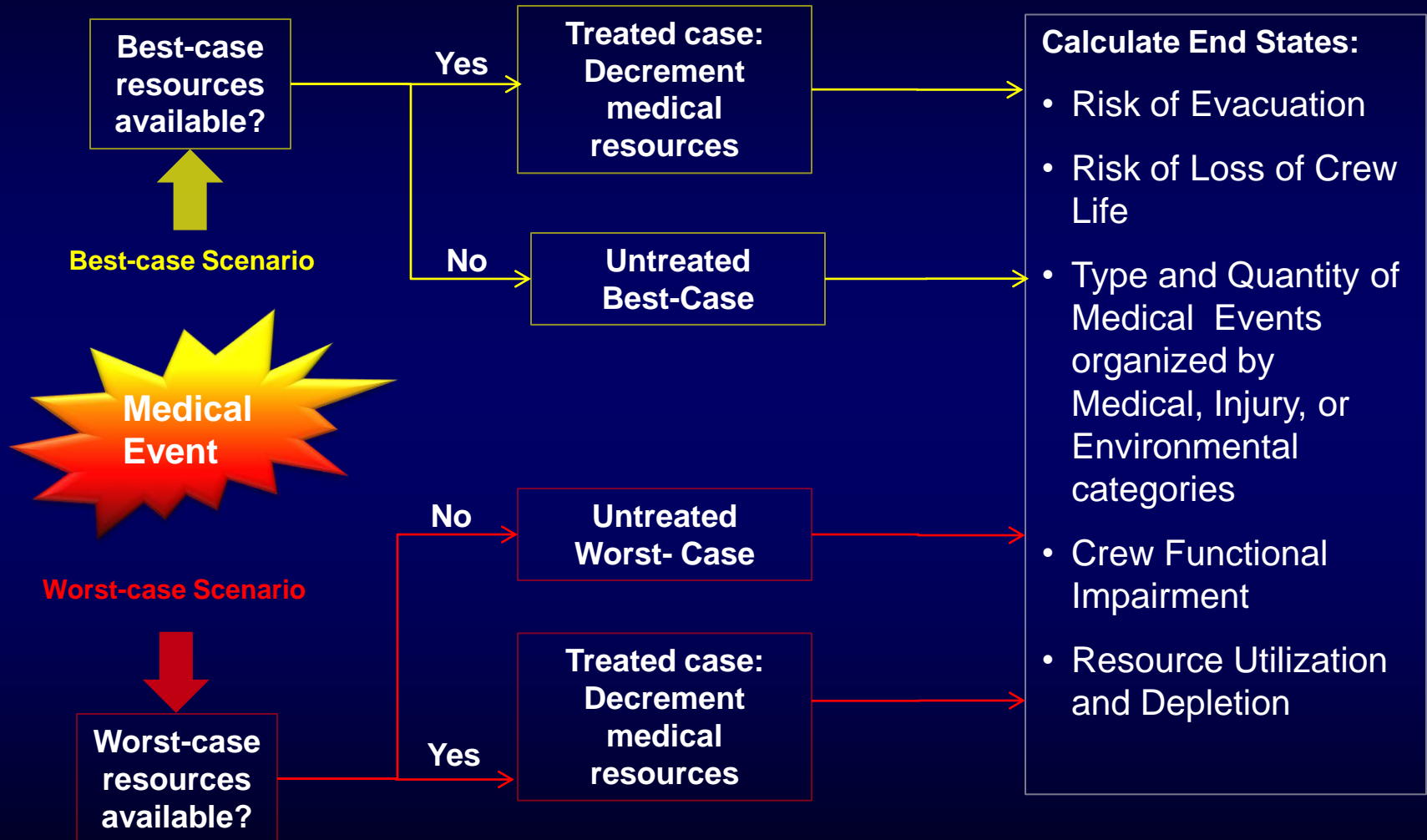
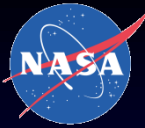
▪ Crew Impairment, Mission and Clinical End States

▪ Resources used

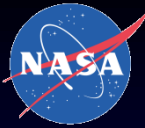
▪ Optimized medical system within vehicle constraints



# Event Sequence Diagram



# Status of IMM



- Past Uses of the IMM
  - ISS medical system re-design
  - IV Fluid “What if” Assessment
  - Storage Capacity Requirements of Vomitus/Diarrhea for Constellation
  - Constellation medical kit design support
  - ISS Emergency Return Vehicle Analysis
  - Near Earth Asteroid Mission Support (HEFT DRM4)
- Validation and Verification of clinical data
- Documentation of methods and innovations
- Migrating clinical evidence to IMM database
- Establishing web-based external review capability
- Enhancing database reporting capabilities

# Verification & Validation (V&V) Status

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- Established and implemented V&V Plan
- V&V Plan includes internal and external reviews
- Key IMM elements identified for V&V
- V&V Plan approved via the NASA STD 7009 process
- Established NASA STD 7009 Credibility and Compliance Matrixes for IMM

# Verification & Validation (V&V) Status

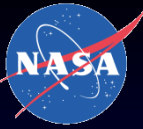


IMM Element	Internal Review	External Review (NASA or non-NASA)	External Review (non-NASA)
IMM medical conditions list	✓	✓ a) panel b) individual SMEs	Pending
Internal Clinical V&V process	✓	✓ (non-NASA)	
Clinical Inputs (incidence, health impairment, mitigation, consequences, etc.)	30%	Pending (Selected Medical Conditions)	Pending (Selected Medical Conditions)
Model programming	✓	Pending (non-NASA)	
Software and code documentation	✓	Pending (non-NASA)	
IMM database process	✓	✓ (non-NASA)	
IMM output components	✓	✓	
IMM overall approach	✓	✓	✓
IMM output results	✓	✓ a) panel b) individual SMEs	

- Reference Mission (as defined by ISS PRA Group)
  - 6-person crew (1 female, 5 males)
  - 6-month mission
  - 3 EVAs total for mission
- Industry standard statistical software, SAS 9.1
- Monte Carlo simulations (100K trials)
- Fully-treated scenario using the ISS medical system

# Key Assumptions and Limitations

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- Accurate diagnosis of all medical events
- Treatments are effective
- 100% reliable medical equipment
- All medical events occur on day one of mission

# IMM Definition of Medical Evacuation

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- Evacuation is considered as the mission end state when the medical event has the potential to result in any of the following
  - Loss of crew life
  - Permanent impairment
  - Intractable pain or suffering
  - Inability to complete mission critical tasks
  - Persistent disturbance of behavior, thought or mood that may lead to harm to self or others (psychiatric emergency)

# Results – EVAC and LOC



## ISS Reference Mission - Fully Treated

Category	EVAC	EVAC (%)	95% CI
Medical Illness	<b>1 in 32</b>	3.14	2.97-3.32
Injury/Trauma	<b>1 in 169</b>	0.59	0.52-0.67
Environmental	<b>1 in 135</b>	0.74	0.65-0.81
<b>All Conditions</b>	<b>1 in 23</b>	<b>4.43</b>	<b>4.25-4.61</b>

Category	LOC	LOC (%)	95% CI
Medical Illness	<b>1 in 270</b>	0.37	0.31-0.43
Injury/Trauma	<b>1 in 769</b>	0.13	0.10-0.16
Environmental	<b>1 in 172</b>	0.58	0.49-0.65
<b>All Conditions</b>	<b>1 in 94</b>	<b>1.06</b>	<b>0.97-1.16</b>

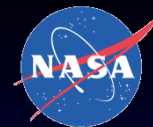


# Conversion of % EVAC to events/person-yr



- IMM forecasts a **4.43%** probability of EVAC for a 6 crew/6 month ISS mission
  - 6 crew x 0.5 years (6 months) = 3 person-yrs
  - 0.0443 events/3 person-yrs = **0.015 events/person-yr**
- IMM forecasts a **1.06%** probability of LOC for a 6 crew/6 month ISS mission
  - 6 crew x 0.5 years (6 months) = 3 person-yrs
  - 0.0106 events/3 person-yrs = **0.0035 events/person-yr**

# Comparison of *Risk of EVAC* Rates



**IMM forecasted *Risk of EVAC* rate (0.015) compares favorably with literature review EVAC rates (0.010 to 0.072)**

Source	Low (events/person-yr)	Max (events/person-yr)
IMM (mean)	0.015	-
ISS PRA (mean)	0.001	-
ISS Independent Safety Task Force (February 2007)	0.028	0.042
Terrestrial General Population	0.060	-
Antarctic Population	0.036	-
U.S. Submarine Population	0.023	0.028
Russian Historical Space Flight Data	0.032	0.072
LSAH (Astronaut Health) Data	0.010	0.020
SSF Clinical Experts Seminar Proceedings (1990)	0.010	0.030

# Validation - Risk of EVAC



## IMM Simulation Data

### Medical illness (71%)

1. Dental Abscess
2. Sepsis
3. Kidney Stones
4. Stroke
5. Atrial Fibrillation
6. Acute Chest Pain/Angina

### Injury/Trauma (13%)

1. Hypovolemic Shock
2. Wrist Fracture

### Environmental (16%)

1. Smoke Inhalation
2. Toxic Exposure

## Actual Russian Flight Data

### Three EVACs

1. Urosepsis
2. Cardiac Arrhythmia
3. Smoke Inhalation

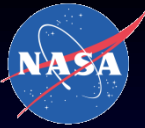
### Three Close Call EVACs

1. Kidney Stone
2. Dental Abscess
3. Toxic Exposure

**NOTE: No Russian data are in IMM**

# Recent Medical Events

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- Although papilledema and ocular issues have come to the forefront, currently there is not enough knowledge to know when or if this problem could reach the level requiring evacuation. As data becomes available, it will be added to the model.

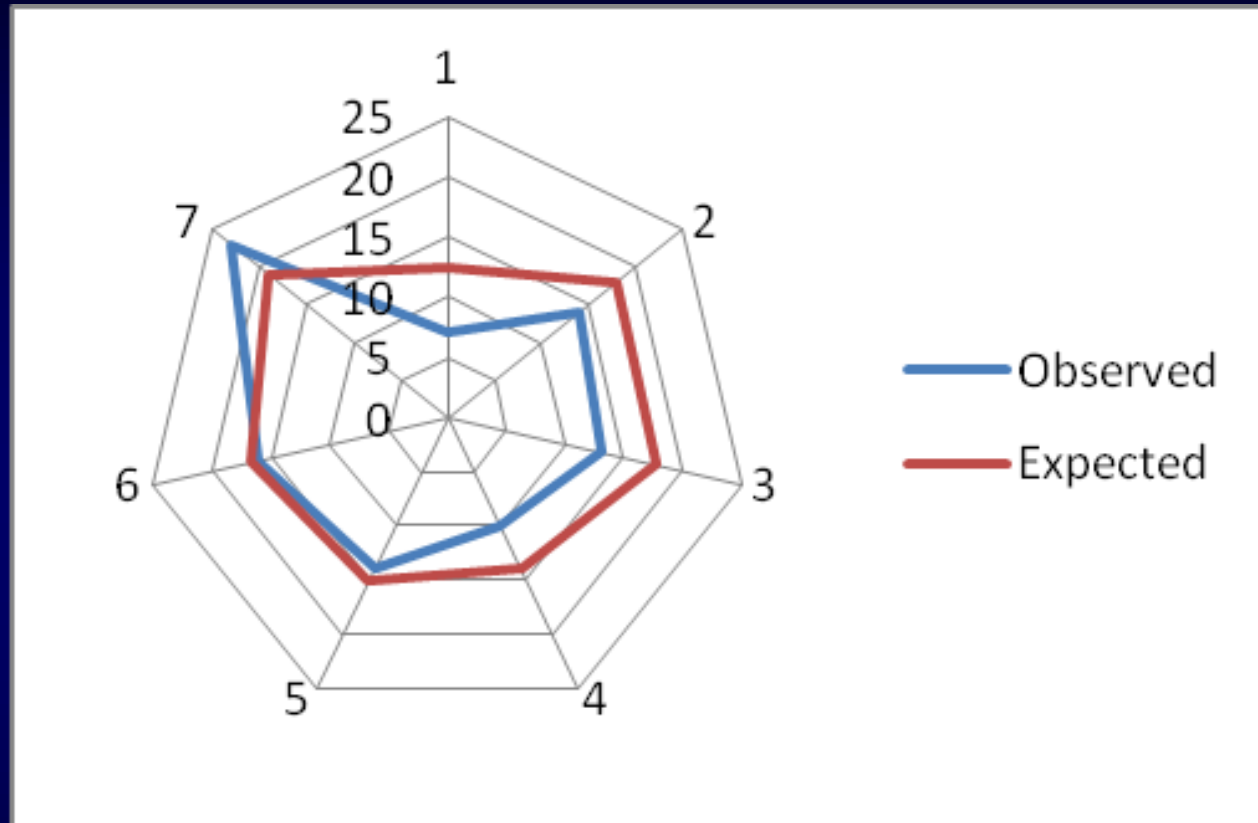
# Validation – *Risk of LOC* forecast



**IMM forecasted *Risk of LOC* rate (0.0035) compares favorably with literature review results for LOC rates (0.0028 to 0.0081)**

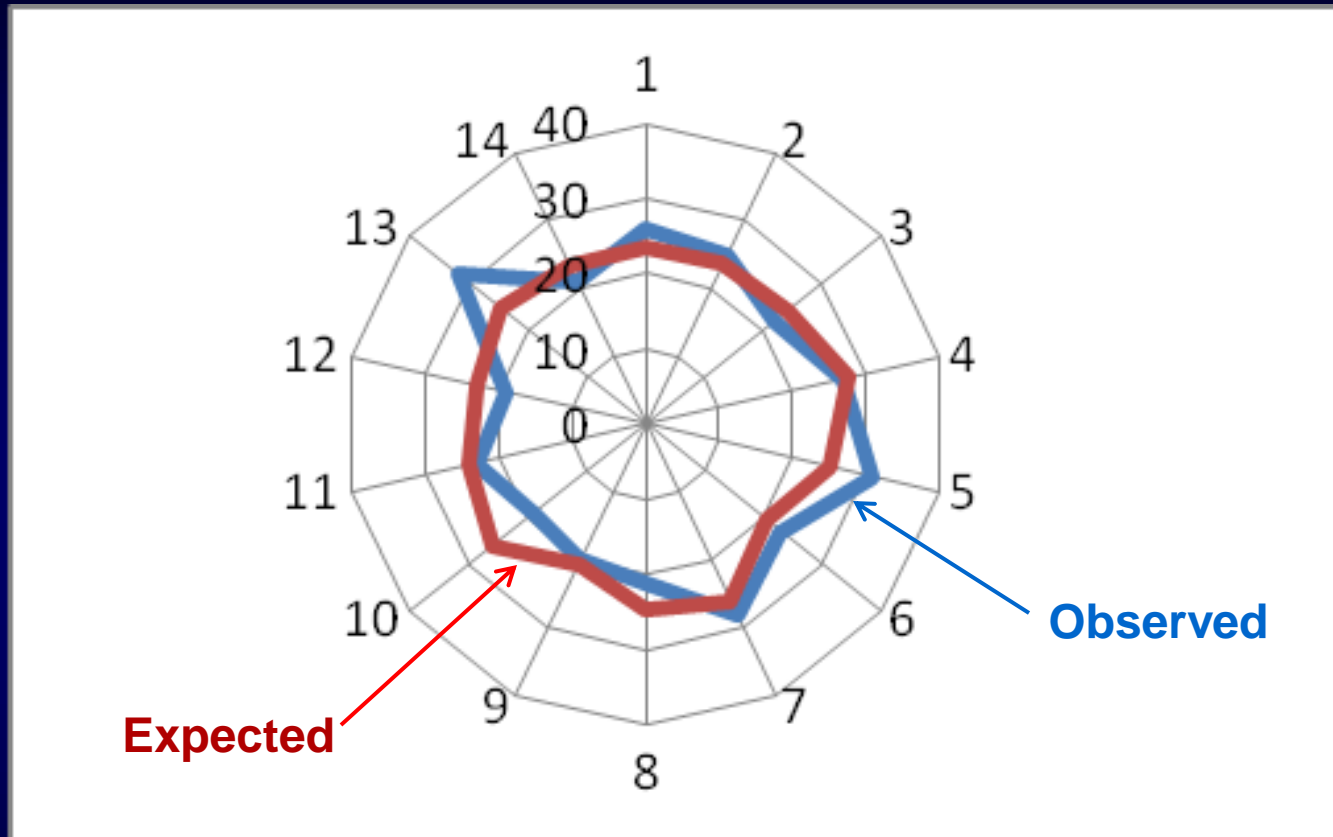
Source	LOC (events/person-yr)
IMM (6 crew/6-month mission)	0.0035
ISS PRA (3 crew/6-month mission)	0.0006
Terrestrial Mortality Rate	0.0081 (2006)
48-year old male	0.0047 (2006)
48-year old female	0.0028 (2006)
Antarctic	0.0054 (1904-1964)
LSAH Data	0.0034 (1980-2009)

# Validation – ISS Medical Event Estimates



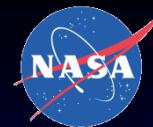
Spider plot comparing the observed (historical data) and expected (model data) number of medical events by mission – ISS (Source: *IMM Validation - Goodness of Fit Report for ISS and Shuttle Missions, JSC #TBA*)

# Validation – Shuttle Medical Event Forecasts



Spider plot comparing the observed (historical data) and expected (model data) number of medical events by mission – Shuttle (Source: IMM Validation - Goodness of Fit Testing for ISS and Shuttle Missions, JSC #TBA)

# Summary of Validation



## ***Risk of Evacuation (EVAC) Estimates***

Source	Low (events/person-year)	Max (events/person-year)
IMM (mean)	0.015	-
ISS PRA (mean)	0.001	-
Evidence-based Literature	0.010	0.072

## ***Risk of Loss of Crew Life (LOC) Estimates***

Source	Low (events/person-year)	Max (events/person-year)
IMM (mean)	0.0035	-
ISS PRA (mean)	0.0006	-
Evidence-based Literature	0.0028	0.0081



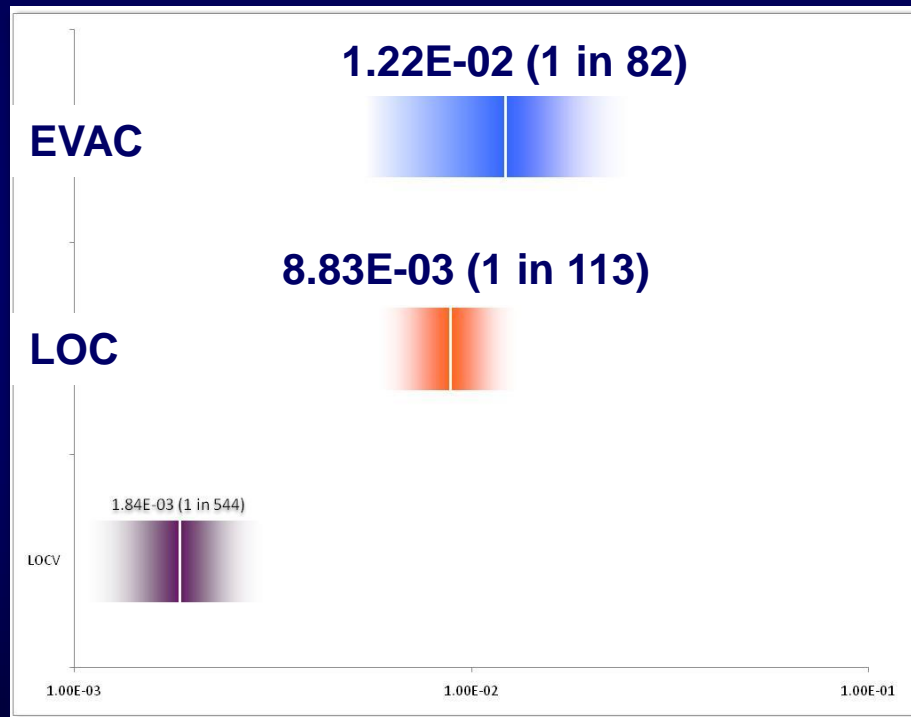
# Comparison of Data – IMM vs. ISS PRA

Source Model	Risk of EVAC*	Risk of LOC*
IMM (mean)	0.015 (4.43%)	0.0035 (1.06%)
ISS PRA (mean)	0.001 (0.35%)	0.0006 (0.17%)
Difference	x15 factor	x5.8 factor

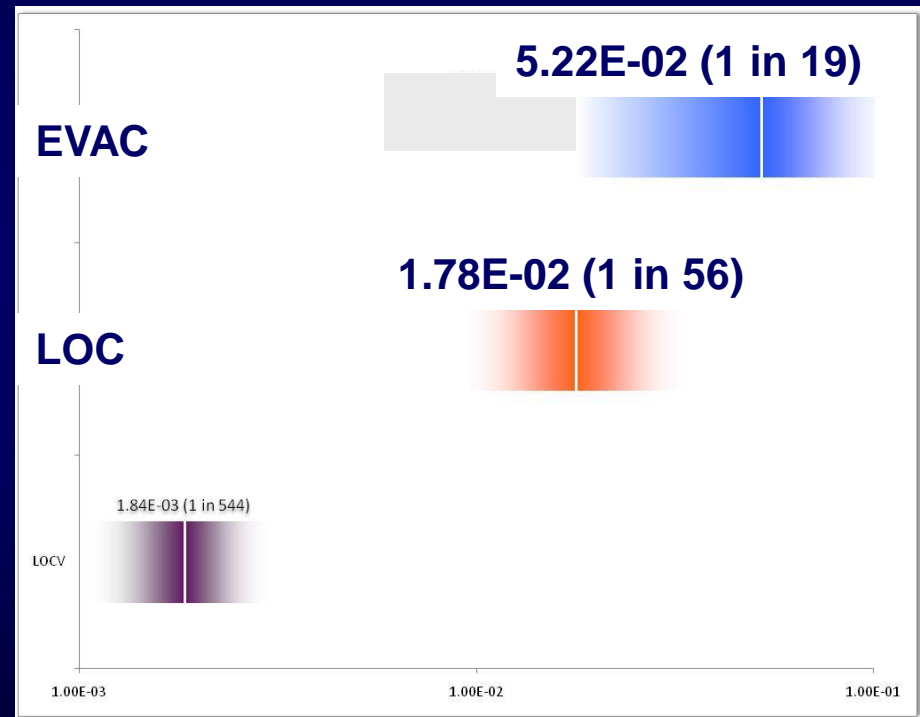
\* Shown as events/person-year, and percent during mission

# Impact to ISS PRA

## PRA 2.1.1

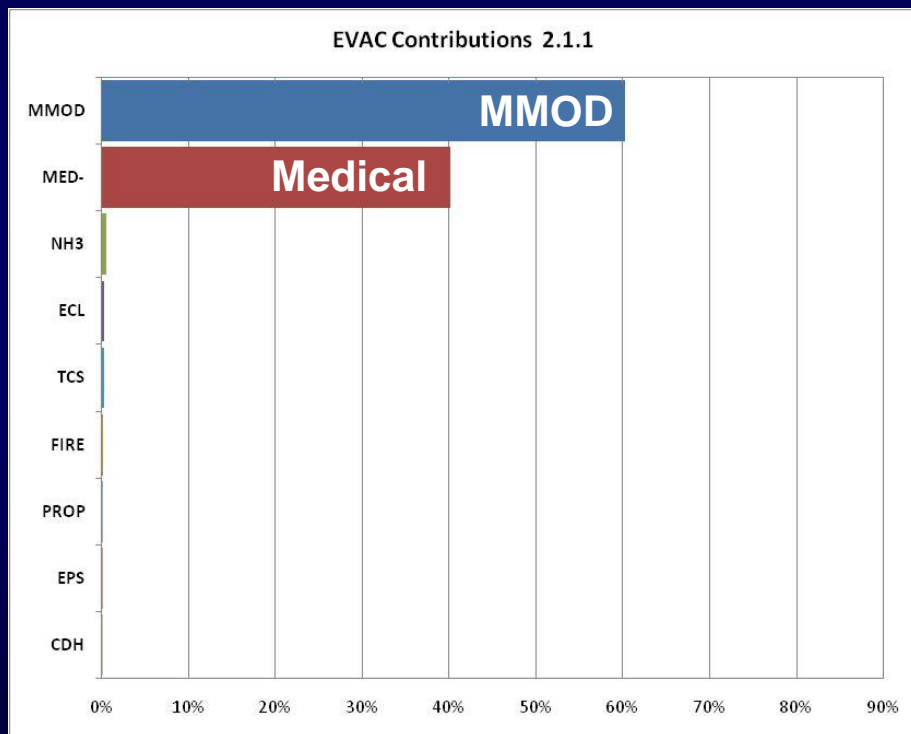


## PRA 2.1.1 with IMM

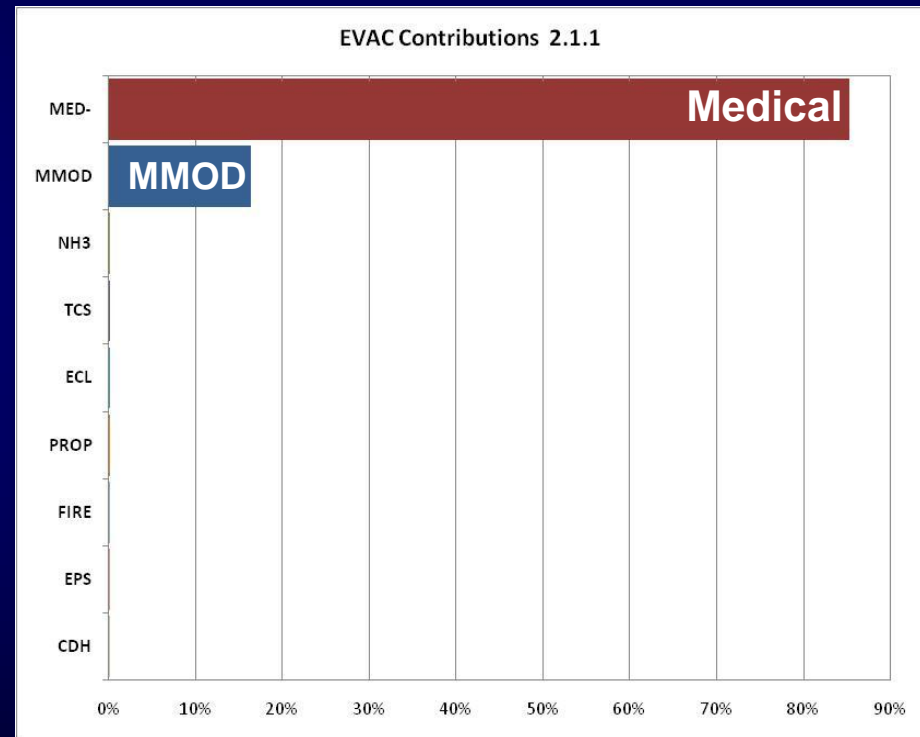


# Impact to ISS PRA - EVAC

## EVAC PRA 2.1.1

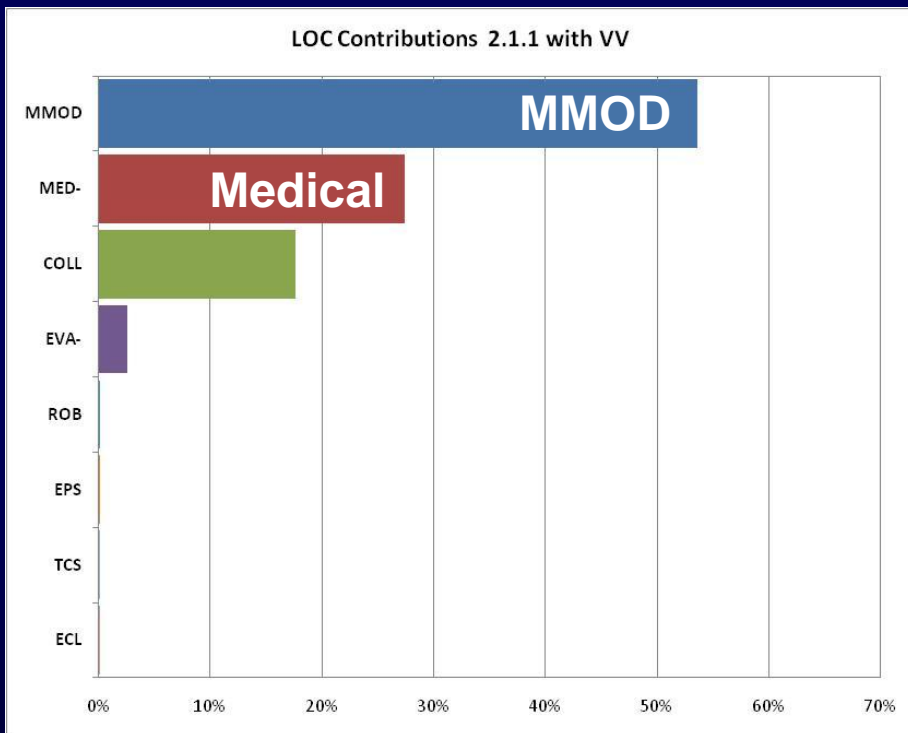


## EVAC PRA 2.1.1 with IMM

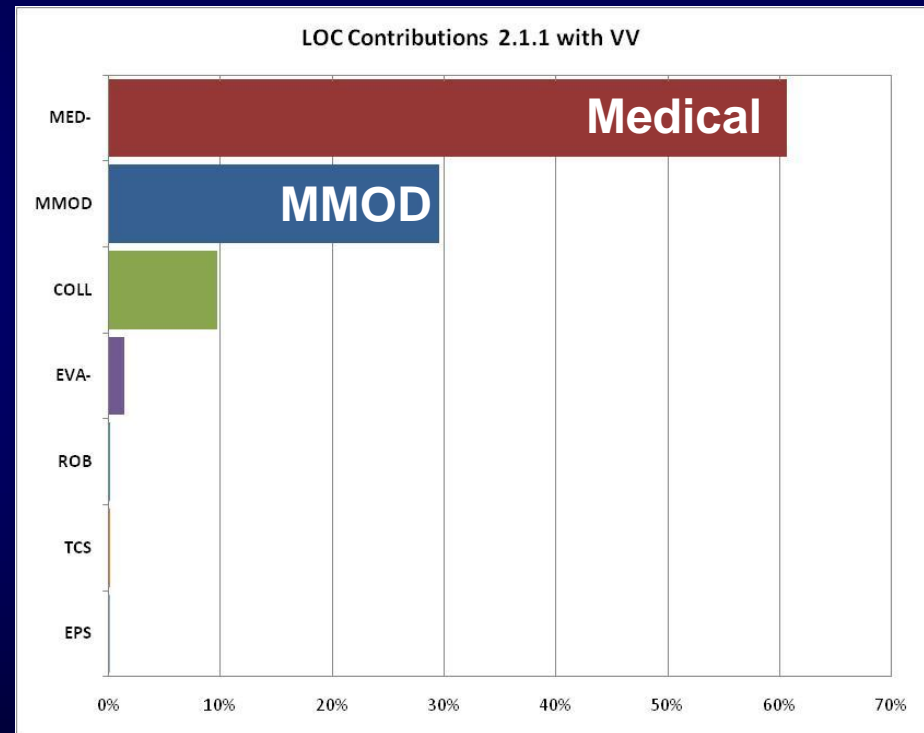


# Impact to ISS PRA - LOC

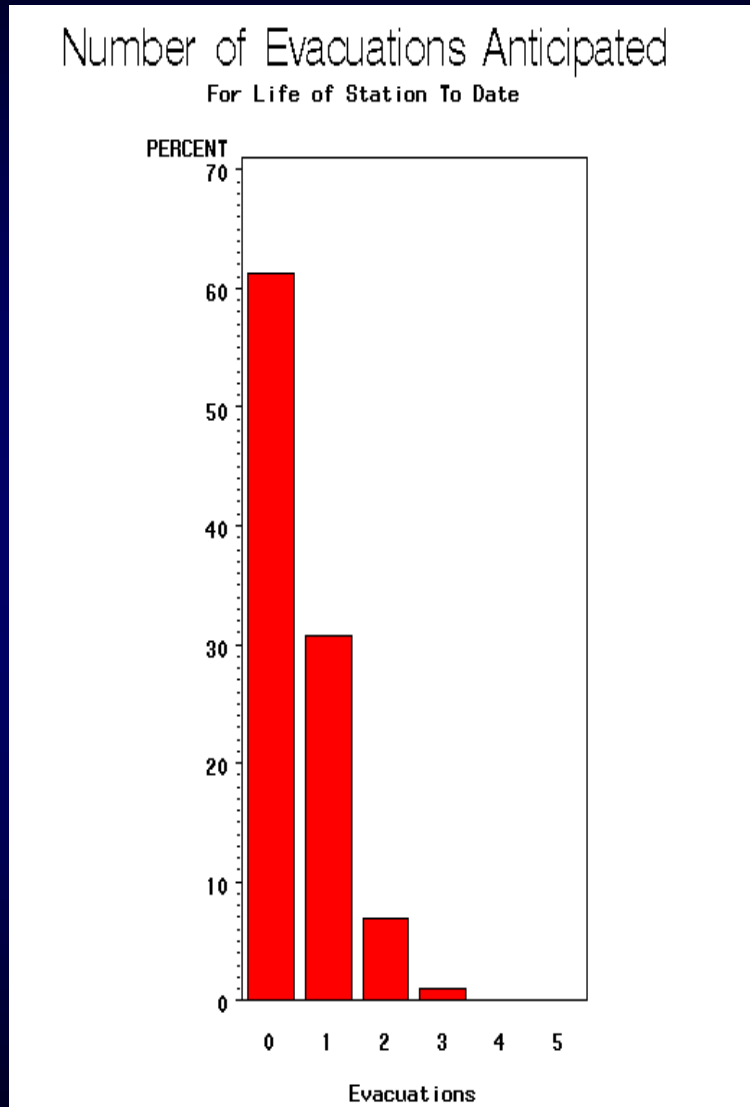
## LOC PRA 2.1.1



## LOC PRA 2.1.1 with IMM



# Forecast of Medical Evacuations on ISS To Date



- 61% probability of no medical evacuation to date
- 39% probability of one or more medical evacuations to date
- Assumes a 4.43% probability of evacuation for a 6-crew, 6-month increment.
  - 3 person-years per increment
- Assumes 33 person-years of ISS crew time to date.

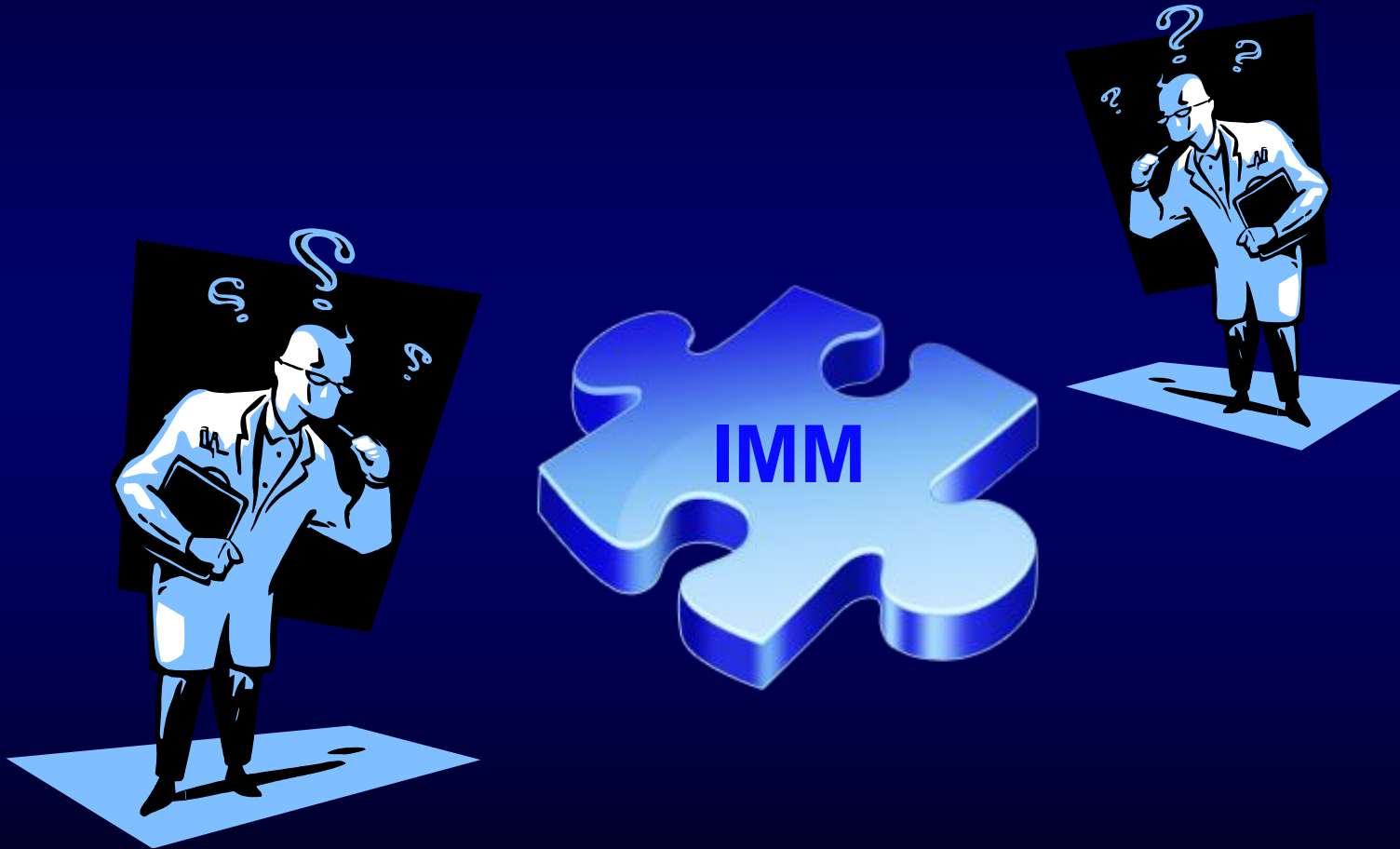
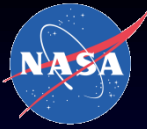
# Closing

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- Medical events will be lead contributor to “Risk of EVAC/LOC”, surpassing ISS PRA estimates of “Risk of EVAC/LOC” from MMOD
- A comprehensive evidence review forms the basis for updating the ISS PRA Risk Model

# Open Discussion and Questions



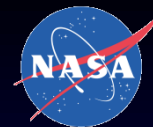
# Back-Up Slides

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# Updated ISS PRA EVAC and LOC Forecasts



Probabilities at least one EVAC or LOC

Timeframe	Med EVAC Probability	Total EVAC Probability	Med LOC Probability	Total LOC Probability
ISS to Date	39%	44%	11%	18%
<b>ISS to 2020</b>	<b>74%</b>	<b>79%</b>	<b>27%</b>	<b>42%</b>

# Emergent Evacuation



## IMM Results from Emergency Return Vehicle Trade Study (May 2010)

Estimated Emergent EVAC Probability = 1.2%

1. Kidney Stone	0.33%
2. Smoke Inhalation	0.22%
3. Toxic Exposure	0.20%
4. Sepsis	0.15%
5. Hypovolemic Shock	0.10%

**Note: Based on 3 crew/6 month ISS mission**

# Environmental Risk Discussion

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- Environmental Conditions in IMM
  - **Smoke Inhalation**
  - **Toxic Exposure**
  - Acute Radiation Syndrome
  - Altitude Sickness
  - Barotrauma (ear/sinus block)
  - Burns
  - Decompression Sickness (EVA)
  - Headache (CO<sub>2</sub> induced)



- Differences between ISS PRA and IMM
  - IMM estimates the incidence of smoke inhalation and toxic exposure based on historical data of crew medical events
  - ISS PRA estimates the incidence of smoke inhalation and toxic exposure based on the probability of ISS system failures
  - Since the ISS PRA does not consider the medical risk of smoke inhalation and toxic exposure, it is valid to include these conditions in the IMM as contributors to the risk of EVAC and LOC

# IMM Intravenous Fluids (IV) Analysis

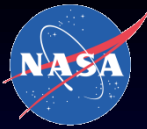


Outcome	IV Fluids	No IV Fluids *
CHI (%)	93.79	93.48
EVAC (%)	3.64	7.26
LOCL (%)	1.09	2.40

Outcomes are based on a 6 month/6 crew ISS mission

\* Conservative (high) estimates of outcomes based on IMM limitation that medical conditions requiring IV fluids go untreated

# Validation of Dental Evacuation



Outcome	IMM	Military *
Dental Evacuation (events/person-yr)	0.006	0.017

## \* References

Chaffin, et al. Review of Current U.S. Army Dental Emergency Rates. Military Medicine, 173, 1:23-26, 2008.

Deutsch, et al. Dental Events during Periods of Isolation in the U.S. Submarine Force. Military Medicine, 173, 1:29-37, 2008.

# Medical Conditions in IMM by Category



## Medical Illness

Acute Chest Pain/Angina	Dental Tooth Loss	Nosebleed (SAS)
Acute Prostatitis	Depression	Otitis Externa
Allergic Reaction	Diarrhea	Otitis Media
Anaphylaxis	Eye Abrasion	Pharyngitis
Anxiety	Eye Corneal Ulcer	Seizures
Appendicitis	Eye Infection	Sepsis
Atrial Fibrillation	Gastroenteritis	Sinus Infection
Back Pain (SAS)	Glaucoma	Skin Infection
Behavioral Emergency	Headache (SAS)	Skin Rash
Cardiogenic Shock	Hemorrhoid	Space Motion Sickness (SAS)
Choking (foreign body inhalation)	Indigestion	Stroke
Constipation (SAS)	Insomnia (SAS)	Sudden Cardiac Arrest
Cough (URI/Pneumonia)	Kidney Stones	Urinary Incontinence (SAS)
Dental Abscess	Late Insomnia	Urinary Retention (SAS)
Dental Crown Replacement	Medication OD/Misuse	Urinary Tract Infection
Dental Temporary Filling	Mouth Ulcer/Cold Sore	Vaginal Yeast Infection
Dental Toothache	Nasal Congestion (SAS)	

# Medical Conditions in IMM by Category



## Injury/Trauma

Abdominal Injury  
Back Injury  
Chest Injury/Pneumothorax  
Eye Abrasion  
Eye Penetration  
Elbow Dislocation  
Finger Dislocation  
Fingernail Delamination (EVA)  
Head Injury (TBI)  
Hip/Proximal Femur Fracture  
Hypovolemic Shock  
Lumbar Spine Fracture  
Neck Injury  
Neurogenic Shock  
Paresthesias/Hot Spots (EVA)  
Shoulder Dislocation  
Skin Abrasion/Laceration  
Sprain/Strain  
Wrist Fracture

## Environmental

Acute Radiation Sickness  
Altitude Sickness  
Barotrauma (ear/sinus block)  
Burns  
Decompression Sickness (EVA)  
Eye Chemical Burn  
Headache (CO<sub>2</sub> induced)  
Smoke Inhalation  
Toxic Exposure



# IMM System Diagram

